



# Hub location in air cargo transportation: A case study

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## A B S T R A C T

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This paper models constrained choices when establishing cargo hub and spoke networks. A mixed integer linear programming model is developed introducing additional constraints to the traditional model of uncapacitated multiple allocation hub location problem and empirically tested. The tests suggest that aircraft range and trip cost, runway availability and cargo traffic continuity of an airport are major factors affecting hub locations along with the costs of airline movements.

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## 1. Introduction

Hub systems require different network designs based upon their particular characteristics. Here we introduce the sectorial characteristics of air transportation into the traditional uncapacitated multiple allocation hub location problem (UMAHLP) and develop a new mixed integer linear programming model.

In most of the studies on air transportation applications of hub location problem (HLP), little attention has been given to the value and the components of cost; and in particular direct operating cost (DOC), total operating cost (TOC), fixed and variable costs for aircraft are generally not considered in any detail or with consistency (e.g. Lin et al., 2003; Yang, 2009).

Here we explore the effects of the new constraints and the sectorial characteristics of air transportation on HLP. These constraints can also be used in different fields such as road transportation, computer networks etc. The model developed, by including the new constraints, is tested using two data sets.

## 2. The model

Our analysis involves modified Ebery et al.'s (2000) multiple allocation version of the capacitated hub location problem (the "EA Model") by including additional constraints (the "New Model"). In both models, the capacity constraint is removed and the objective function 1 is used under the constraints 2–11 for the New Model and constraints 2–6, 10 and 11 for the EA Model.

$$\min \sum_{i \in N} \left[ \sum_{k \in N} CT_{ik} Z_{ik} + \sum_{k \in N} \sum_{l \in N} \alpha CT_{kl} Y_{kl}^i + \sum_{l \in N} \sum_{j \in N} CT_{lj} Y_{lj}^i \right] + \sum_k F_k H_k \quad (1)$$

subject to

$$\sum_{k \in N} Z_{ik} = \sum_j W_{ij} \quad (2)$$

$$\sum_{l \in N} X_{lj}^i = W_{ij} \quad \forall i, j \in N \quad (3)$$

$$\sum_{l \in N} Y_{kl}^i + \sum_{j \in N} X_{kj}^i - \sum_{l \in N} Y_{lk}^i - Z_{ik} = 0 \quad \forall i, k \in N \quad (4)$$

$$Z_{ik} \leq O_i \cdot H_k \quad \forall i, k \in N \quad (5)$$

$$X_{lj}^i \leq W_{ij} \cdot H_l \quad \forall i, j, l \in N \quad (6)$$

$$d_{ik} \cdot H_k \leq S \quad \forall i, k \quad (7)$$

$$T \cdot H_k \leq Wa_{(m,k)} \quad \forall m, k \quad (8)$$

$$H_k \leq RA_k \quad \forall k \quad (9)$$

$$H_k \in \{0, 1\} \quad \forall k \quad (10)$$

$$X_{lj}^i, Y_{kl}^i, Z_{ik} \geq 0 \quad \forall i, j, k, l \in N \quad (11)$$

where;  $N$  is the set of nodes,  $W_{ij} \geq 0$  is the flow from the origin  $i$  to the destination  $j$  for all,  $CT_{ij}$  is the unit trip cost from  $i$  to  $j$ ,  $RA_k$  is the appropriateness of node  $k$  to be a hub,  $F_k$  is the fixed hub cost of node  $k$ ,  $S$  is the maximum link distance,  $T$  is the minimum required traffic flow of node  $k$ ,  $Wa_{(m,k)}$  is the flow of node  $k$  in time period  $m$  and  $\alpha$  is the interhub discount factor. The decision variables used are given likewise:  $H_k = 1$  if node  $k$  is a hub and

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**Table 1**  
The annual cargo traffics of Turkish airlines in 2006.

Airport name	IATA codes	Annual cargo traffic (Ton)
Istanbul Ataturk	IST	31.155
Izmir Adnan Menderes	ADB	12.241
Ankara Esenboga	ESB	8.802
Adana	ADA	5.096
Antalya	AYT	3.545
Trabzon	TZX	1.402
Dalaman	DLM	439
Gaziantep	GZT	359
Diyarbakir	DIY	327
Istanbul Sabiha Gokcen	SAW	321
Milas-Bodrum	BJV	265
Kayseri	ASR	225
Malatya Erhac	MLX	223
Erzurum	ERZ	182
Van Ferit Melen	VAN	148
Denizli Çardak	DNZ	52
Kars	KSY	47
Elazığ	EZS	28

0 otherwise,  $Z_{ik}$  is flow from origin  $i$  to hub  $k$ ,  $Y_{kl}^i$  is flow from origin  $i$  and routed via hubs  $k$  and  $l$  and  $X_{ij}^i$  is flow from node  $i$  to node  $j$  via hub  $l$ .

The objective function that minimizes the costs includes the trip and fixed hub costs. Constraints 2–4 represent the flows originating from node  $i$ . Constraint 5 prevents the directing of flows to a non-hub node. Constraint 6 blocks the flows between the non-hub nodes. Constraint 7 keeps the distances between nodes and hubs smaller than the maximum link distance. Constraint 8 assures that a node will not be designated as a hub if the traffic flow is less than a certain amount  $T$ . Constraint 9 guarantees that a node will not be designated as a hub if its capability does not meet the pre-defined requirements. Constraint 10 is an integer constraint and constraint 11 ensures that the decision variables related to the traffic flows will be positive. The new constraints 7–9 are included to the traditional model.

### 3. Data

Data from the air cargo market in Turkey are used to test the model. Because airlines refrain from sharing their data, especially relating to the costs and traffic flows, for commercial reasons, trip costs, fixed hub costs (FHC) and cargo traffic statistics between airports could not be obtained from the same carrier. The data used, that we call “Turkish Air Cargo” (TAC) contains the air cargo flows, the flight distances between airports and unit trip costs and was provided by two cargo carriers. Since the transportation cost decreases with trip distance in air transportation, the trip cost is used instead of the transportation cost differentially with the similar data sets.

**Table 2**  
The elements of operating costs.

Total operating cost (TOC)		
Indirect operating cost (IOC)	Direct operating cost (DOC)	
	Fixed operating cost (FOC)	Variable operating cost (VOC)
Facility	Aircraft lease/owning	Fuel and oil
Staff	Flight crew	Navigation fees
Marketing	Maintenance	Airport fees
Administration	Insurance	
	Handling, dispatch fees	

**Table 3**  
UMAHLP analysis results for F27-500.

Analysis	FHC (x\$1000)	Model	Cost (x\$M)	Hubs
1	50	EA Model	26.49	ADA, ADB, AYT, DIY, ESB, GZT, IST, TZX
2	50	New Model	44.54	ADA, ESB, TZX
3	100	EA Model	26.80	ADA, ADB, AYT, ESB, IST, TZX
4	100	New Model	44.69	ADA, ESB, TZX
5	200	EA Model	27.38	ADA, ADB, AYT, ESB, IST
6	200	New Model	44.99	ADA, ESB, TZX
7	500	EA Model	28.72	ADA, ADB, ESB, IST
8	500	New Model	45.89	ADA, ESB, TZX
9	1000	EA Model	30.24	ESB, IST
10	1000	New Model	47.06	ADA, ESB

The model is tested using the cargo statistics of Turkish Airlines, the largest air passenger and cargo carrier in Turkey. Its domestic air cargo for 2006 is given in Table 1. Although Turkish Airlines flew to 32 airports, air cargo was only handled at 18, with 96% of the traffic involving six located in highly industrialized cities; basically regional hubs.

Table 2, shows the standard breakdown of TOC of an air carrier; we subsequently take TOC as the “trip cost”. IOC and the FOC are taken as constant for each trip because they are assumed independent of distance and flow. The most important element in the VOC is the fuel cost that depends on flight phase, aircraft speed and weight, flight level, meteorological conditions, and flight hours. Navigation fees change according to aircraft weight and flight distance, while airport fees depend on aircraft weight and airport category. The unit trip cost (\$/ton) is found by dividing the trip cost by aircraft payload. In the calculation of unit trip costs for an A300-B4 and an F27-500, data for 2006 was obtained from the MNG Air Cargo Company that operates nine cargo aircraft.

FHC consist of facility ownership/rental costs, equipment costs, and ground staff costs that are affected by the aircraft fleet, air cargo, salaries and the operational policies of airline and the category of hub airport. The values of FHC are increased gradually.

The trip costs for F27-500s are assumed to vary between \$2300 and \$11,500 according to flight hours, and between \$5200 and \$19,000 for A300-B4s; the wide body A300-B4, the turboprop aircraft, F27-500 were the most widely used cargo aircraft in Turkey in 2006. The flight distances, times and fuel consumption between airports are calculated using the Graflight program which is also used by many airlines in their cost analyses.

### 4. Results

The constraint of “maximum link distance (Cons.7)” in the New Model for the F27-500 and the A300-B4 at maximum take-off

**Table 4**  
UMAHLP analysis results for A300-B4.

Analysis	FHC (x\$1000)	Model	Cost (x\$M)	Hubs
1	50	EA Model	6.82	ADA, ADB, AYT, ESB, IST
2	50	New Model	6.95	ADB, ESB, IST
3	100	EA Model	7.06	ADA, ADB, ESB, IST
4	100	New Model	7.10	ADB, ESB, IST
5	200	EA Model	7.40	ADB, ESB, IST
6	200	New Model	7.40	ADB, ESB, IST
7	500	EA Model	7.94	IST
8	500	New Model	7.94	IST
9	1000	EA Model	8.44	IST
10	1000	New Model	8.44	IST

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